National Aeronautics and
Space Administration

Advancements in Energy & Power Technologies at NASA Glenn Research Center

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Amazon Energy Team Onsite

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AGENDA

Background

Battery Basics

Up & Coming in the Battery World

NASA Battery & Power Technologies

Interagency Collaborations

Review, Helpful Links & Contacts

BACKGROUND

About Me

- MS ChemE
- NASA Intern Summer ‘08
- Full-time hire ’09
- Battery Tech Lead since 2022
- Led H2 fuel cell bus demo w/local transit authority
- SPARRCI Principal Investigator 2019-2023
- Smudge, Loki, Marble & Michaelangelo
- Enjoy anything sci-fi, reading, nail art, & teaching Zumba

Link!

Bri DeMattia

What Do We Do At NASA Glenn?

- **NASA John H. Glenn Research Center in Cleveland, OH originated as part of NACA in 1942 & became NASA in 1958**
- **~3,000 total employees**
- **Core competencies in:**
  - Air-breathing propulsion
  - Communications technology & development
  - Space propulsion & cryogenic fluids management
  - **Power, energy storage, & conversion**
  - Materials & structures for extreme environments
- **Specialized facilities for engine acoustics, simulated lunar surface, zero-G, wind tunnels, icing research tunnel, large-scale vacuum chambers & planetary simulation**

Photovoltaic & Electrochemical Systems Branch

- The **Photovoltaic & Electrochemical Systems Branch** (LEX) is part of GRC's Power Division and focuses on **photovoltaics, batteries & fuel cell** R&D
- Low (chemistry/materials) to high (battery design, build, testing) level R&D
- Material assessments & battery component optimizations
  - Internal developments and external validation
- Component integration & performance assessments of cells
- Design, build & demonstration of battery designs
- Technology trade studies
- Performance & safety testing
- Oversight on external battery developments (industry/academia)
- Collaborations with other NASA centers, industry, academia, and other government agencies
- Interagency power working groups, federal consortiums, standards development activities for space & aeronautics

Battery Facilities & Capabilities

- 600ft^2 **Dry Room** with 1% relative humidity for handling moisture-sensitive materials
- **Altitude chamber** with temperature & humidity control for aeronautics batteries
- High-temperature furnace for Venus (>450C) testing
- ~20 inert programmable **environmental chambers** for -75C to +200C
- >200 independent battery test channels for **fully unattended testing** of lab-scale cells & large battery modules – up to 400A and 400V
- Wet chemistry labs for fundamental R&D
- **3D printing** capabilities
- Roll-to-roll coater for scaled-up electrode fabrication
- Semi-automated pouch cell stacking equipment
- Glove boxes for inert assembly & **destructive physical analysis**
- Ultrasonic Welder for cell stack welding
- Safety Installations
  - **Blast boxes** for small-scale abuse test containment
  - Cylindrical cell DPA
  - Accelerating Rate Calorimeter for energy release assessments of materials & cells

Historical Battery R&D

- Ni-H2, Ag-Zn, Ni-Cd and other heritage battery technologies
- Performance assessments for replacement Li-ion batteries for the International Space Station
- Multifunctional batteries to integrate into airplane structures
- Li-ion battery development for Mars Exploration Rover

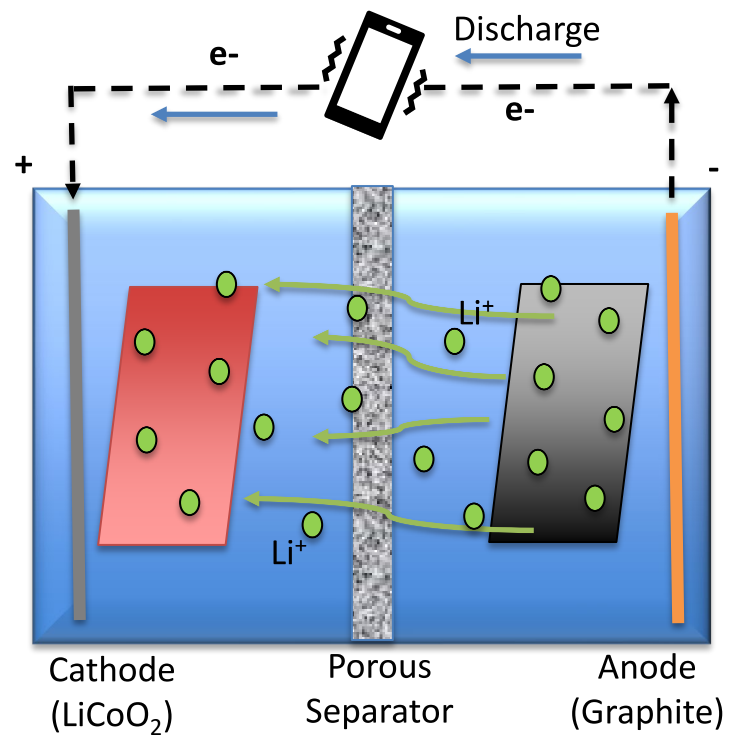
BATTERY BASICS

Battery Basics

- A **battery** is an electrochemical device that converts stored chemical energy into electrical energy
  - A **primary** battery is non-rechargeable (single-use)
  - A **secondary** battery is rechargeable Single unit = cell
- Multiple cells = **battery**
  - Build cells in parallel for added capacity
  - Build cells in series for added voltage

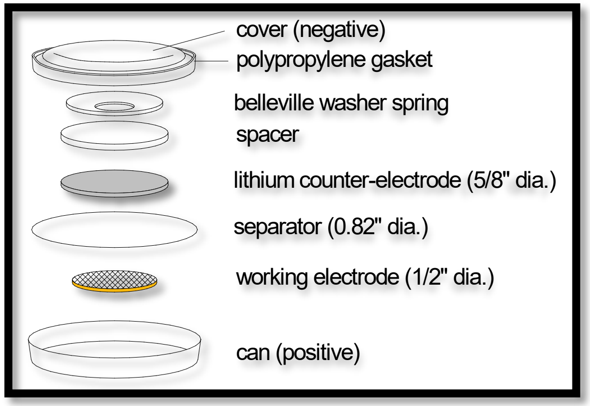
Cell Chemistry

- A **secondary** cell can be recharged for multiple uses
  - Chemical reaction depends on electrode chemistry
    - Ag/Zn, Ni-Cd, Li-ion
  - Voltage is also chemistry-dependent
    - Li-ion 3.6V vs 1.5V for alkaline (AA)
- Components
  - Cathode = positive electrode
  - Anode = negative electrode
  - Electrolyte
    - Ionically conductive medium
  - Separator
    - Physical separation between electrodes, ionically conductive, electrically insulating

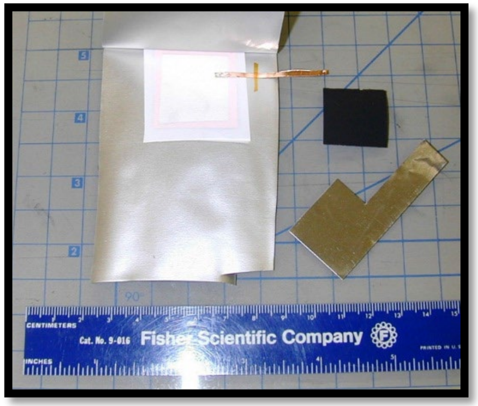


Lab-scale Cell Formats

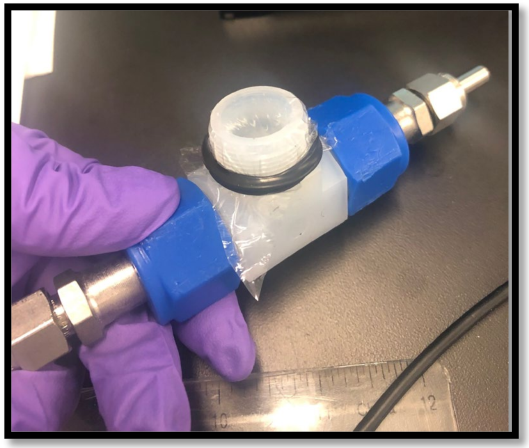
Coin Cell



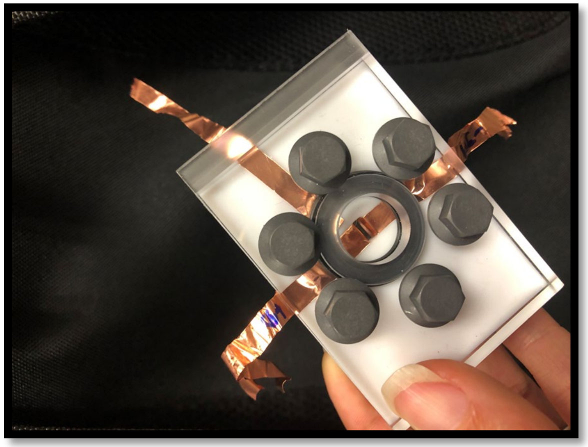
Pouch Cell (single or multi-layer)



Swagelok fitting cell (T-cell)



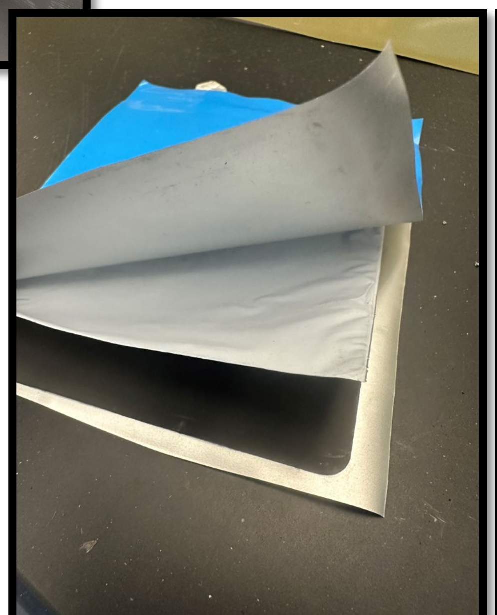
Optical Cell



Scaled-up Commercial Cell Formats

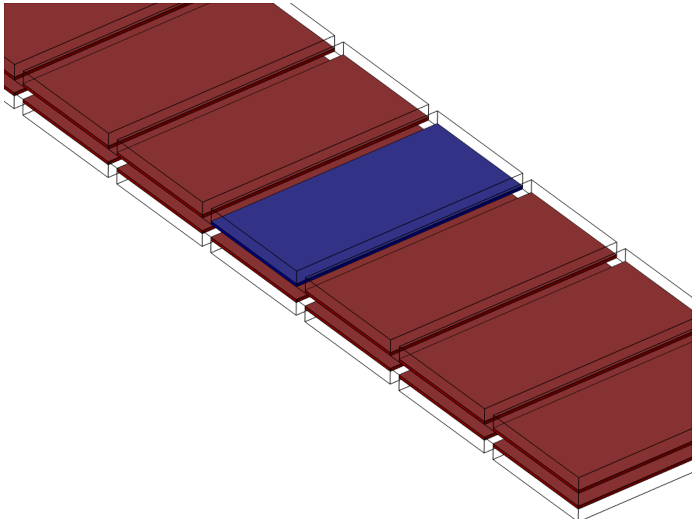
Prismatic (stacked)

Cylindrical (Wound)



Battery System Development

- Battery Management System (BMS) circuitry/software monitors **battery state-of-health**
- **Power management & conversion** to provide power at appropriate specs for end user
- **Thermal** management system & modeling
- Safety design for **thermal runaway** propagation
- **Packaging** for containment, safety, integration



UP & COMING IN THE BATTERY WORLD

Emerging Applications

Electrified Aircraft

- All-electric & hybrid concepts
- Urban Air Mobility & eVTOL
- UAV

Growing Needs for EVs

- Larger vehicles
- Longer range
- Lower cost

Textile Integration

- Wearable energy storage
- Military applications

Beyond EVs

- Electric trains & ships
  - ARPA-E PROPEL-1K

New Cell Formats

- Tesla cylindrical (2170, 4680)
- Blade battery – BYD
- Large-scale pouch cells

Emerging Chemistry & Materials Development

Incremental improvements to Li-ion

- NCA or NMC cathodes
- Silicon composite anodes
  - ALE
- Advanced electrolyte additives
  - NASA JPL

Alternative Metals

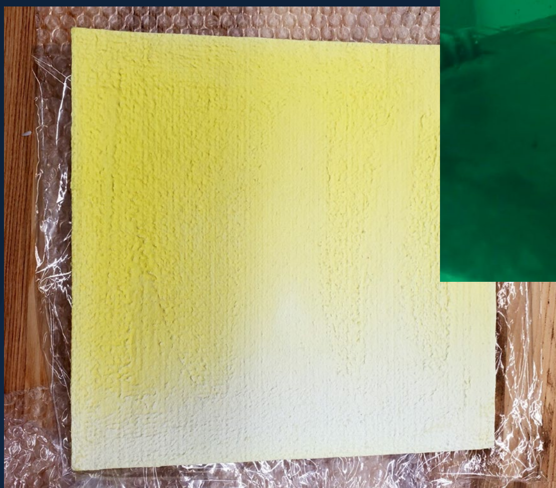
- Na-ion
- Mg-ion

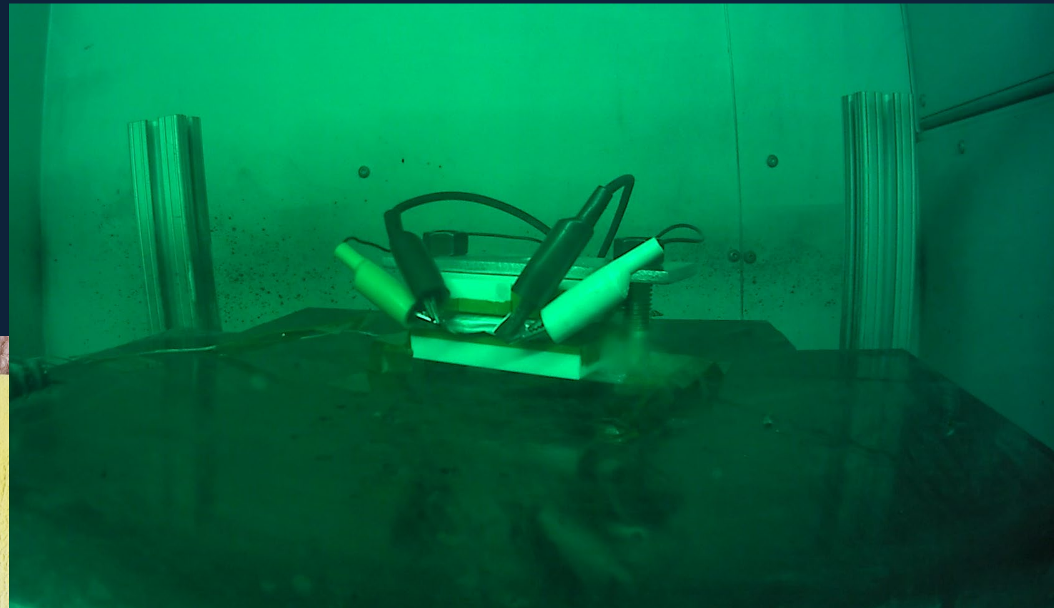
Air-breathing

- Li-air / Li-O_2

Next-gen Chemistries

- Lithium metal secondary
- Solid-state
  - Quantumscape
  - Lyten
  - NASA SABERS
- All-silicon anode
  - Amprius
- Flow batteries

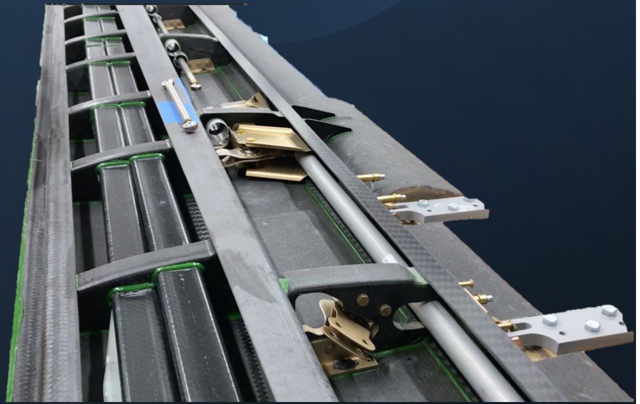




Emerging Materials & Safety

- **Additively Manufactured Packaging**
- **Advanced Thermal Management**
  - Aerogels
  - Heat pipes
  - Phase Change Materials (PCM)
  - Immersion Cooling
- **Thermal Runaway**
  - Passive Propagation-Resistant (PPR) designs

Kinda Out-there Stuff



In-situ Resource Utilization

Sustainability

- Recycling
- Supply chain

Integration Methods

- Next-gen concepts for flexibility & structural integration
- True multifunctional integration
  - NASA M-SHELLS

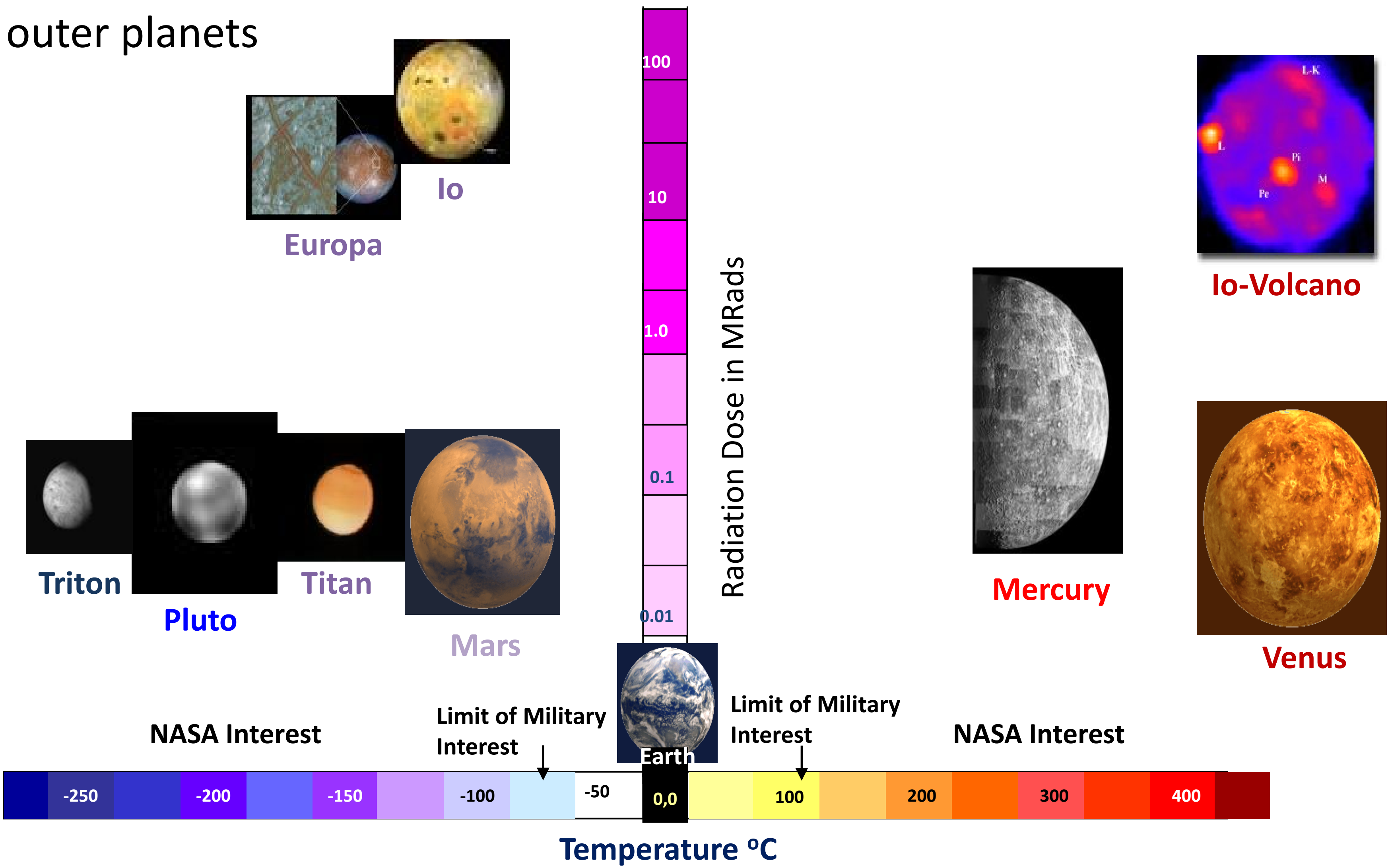
Safety Approaches

- Inherently safe chemistry
- Embedded sensors for health monitoring

NASA BATTERY & POWER TECHNOLOGY DEVELOPMENT

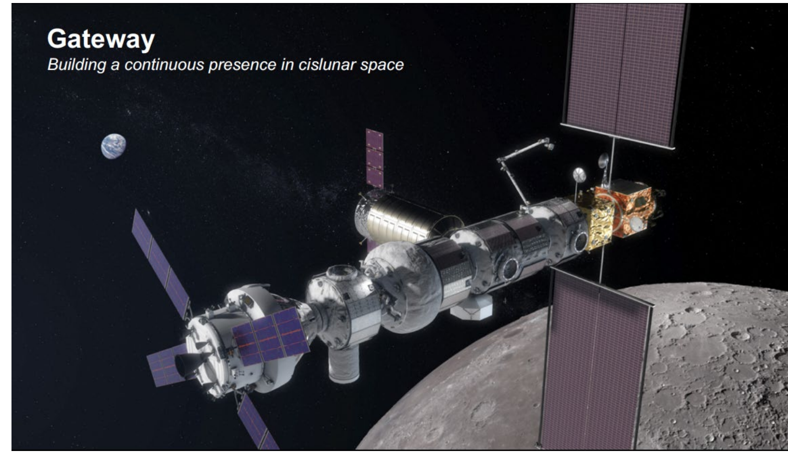
Extreme Environments for NASA Planetary Missions

- NASA missions have unique requirements that span from terrestrial to outer planets



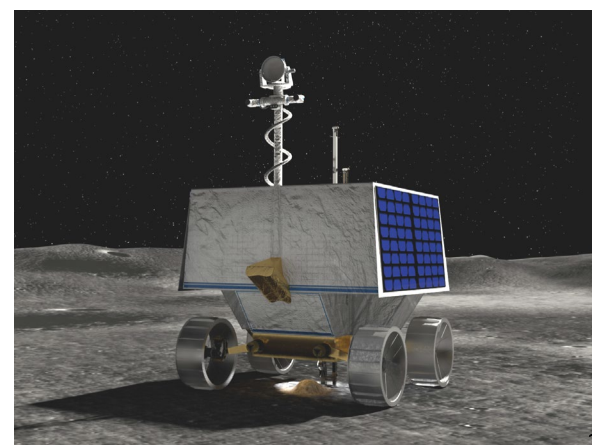
Extreme Environment Energy Storage Development

- **Human Lander Systems (HLS)**
- **Gateway Power & Propulsion Element (PPE)**



- **LLISSE Venus surface missions**

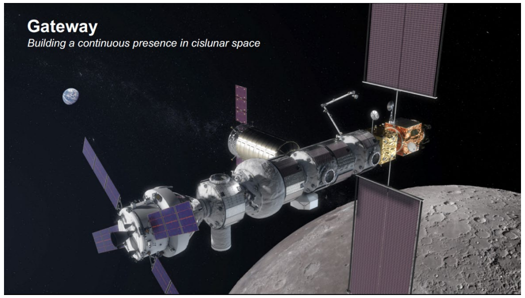
- **Artemis campaign for sustained presence on the Lunar surface**



- **Deep space missions**

Energy Storage/Generation Needs for Lunar Applications

- **14-day eclipse Lunar Night survivability below -200° C and operability beyond -40° C, increased reliability & decreased system complexity**
- **Cislunar Space**
  - Lunar Gateway Power & Propulsion Element
    - 15 year on-orbit operational life
    - 50 kW class spacecraft with 40 kW EP system
- **Lunar Surface**
  - Landers
  - Rovers (> 500 Wh/kg)
  - Permanent habitat power
  - Permanently Shadowed Regions (PSR)
- **EVA suits (> 400 Wh/kg, > 100 cycles)**



Lunar Gateway

Lunar Landers

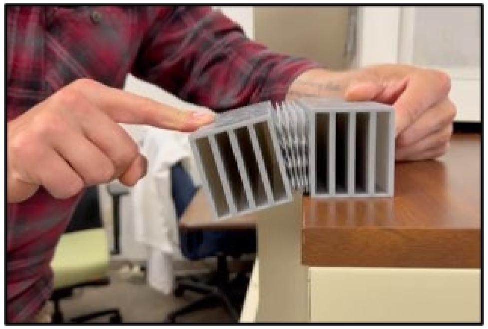
Lunar Rovers

Electric Aircraft Battery Requirements

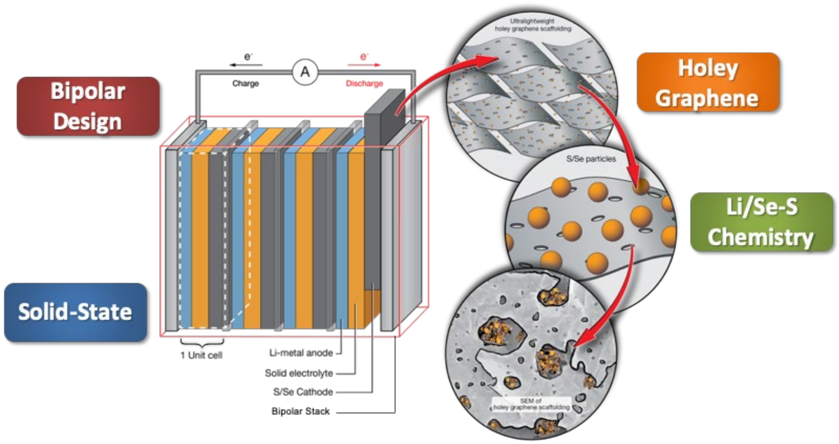
- **> 400 Wh/kg required at the system level**
- **1000’s of cycles with high reliability & limited maintenance**
- **Extreme high power requirements (C-rates) during takeoff and landing**
- **Cruise power for long range flights**
- **< 15-minute fast recharge capability**
- **Improved safety for thermal runaway events**
- **Advanced concepts for packaging, thermal, integration**
- **Concepts for all-electric and hybrid-electric**

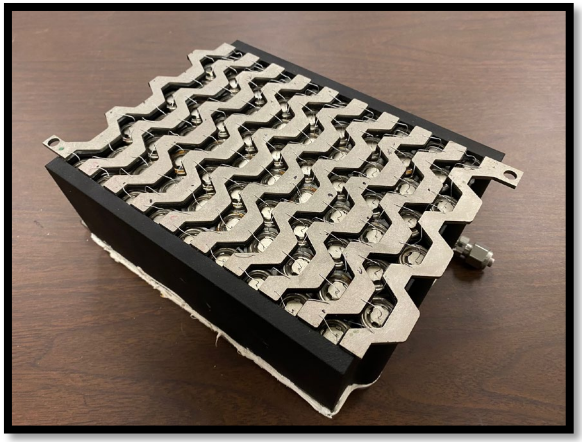
Aeronautics Energy Storage Development

- **Materials, Packaging & Thermal Management – BEAST & SUSAN**
- **Advanced Chemistry R&D – SABERS**
- **Advanced Safety Monitoring – SPARRCI**



Pack-level bending tests to assess survivability of wing integration

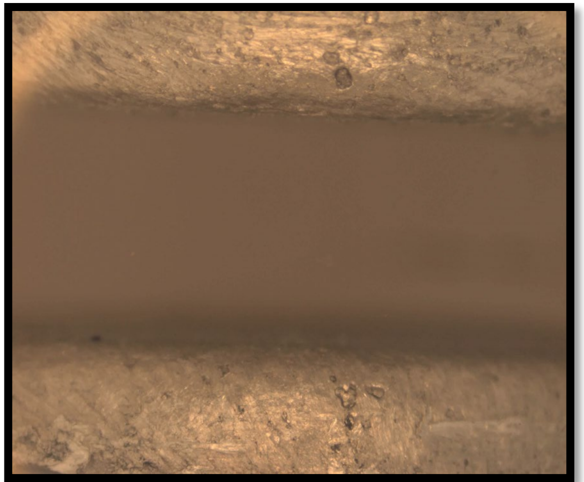




- **Electrified Powertrain Flight Demonstrator (EPFD)**
- **Revolutionary Vertical Lift Technologies (RVLT)**
- **X-57 Flight Demonstrator**

Safety & Thermal Runaway Investigations

- **Decomposition reactions occur in the cell until the temperature rises high enough for uncontrolled exothermic reactions to occur**
  - A single cell thermal runaway can heat surrounding cells, leading to a cascading thermal event that propagates across an entire battery
- **Design to prevent thermal runaway propagation from cell to cell**
  - Level 1: Inherently safe(r) chemistries
  - Level 2: Improved cell safety with shutdown components
  - Level 3: Mitigations at the pack level – thermal, spacing, materials
  - Level 4: Containment



Sensor-based Prognostics to Avoid Runaway Reactions and Catastrophic Ignition

Can catastrophic battery failures be avoided to enable safe next-generation ultra-high energy batteries for propulsive aircraft power?

Battery Failure Analysis

- Off-nominal material morphology studies
- In-situ cell cycling for fault precursors

Sensor Development

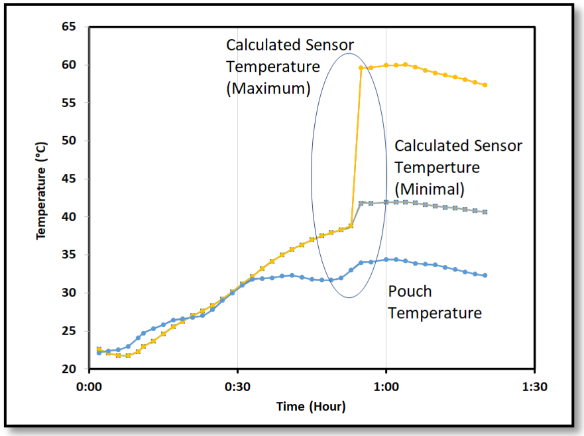
- Embedded sensors for real-time cell state-of-health monitoring

Nondestructive Evaluation (NDE)

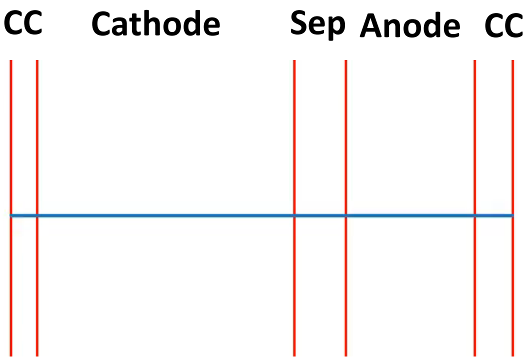
- In-situ and off-line monitoring techniques
- Battery health data without damage
- Advanced modeling & analysis

Modeling & Failure Prognostics

- Multiphysics modeling
- Fault algorithm + failure prognostics
- “Smart” battery management



Embedded sensors for thermal anomaly detection



1D ultrasonic simulation example

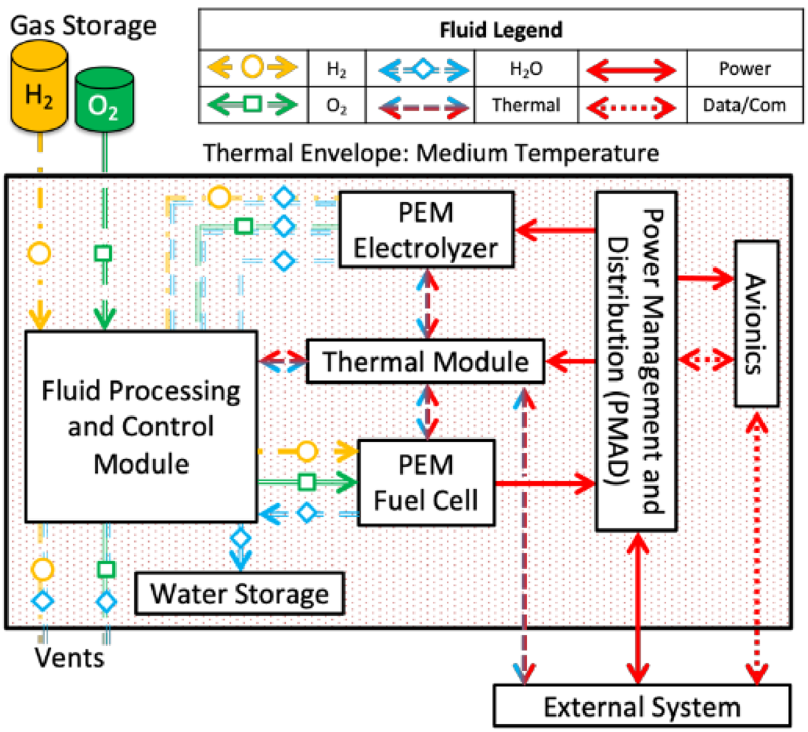
Partners: NASA Glenn (lead), Langley and Ames; Collaborations with Cornerstone Research Group, Inc.

Regenerative Fuel Cell Technology

Technology Product Capability: Provide sustained and reliable electrical power for lunar surface and near-surface missions where photovoltaics/battery or nuclear options may not be feasible

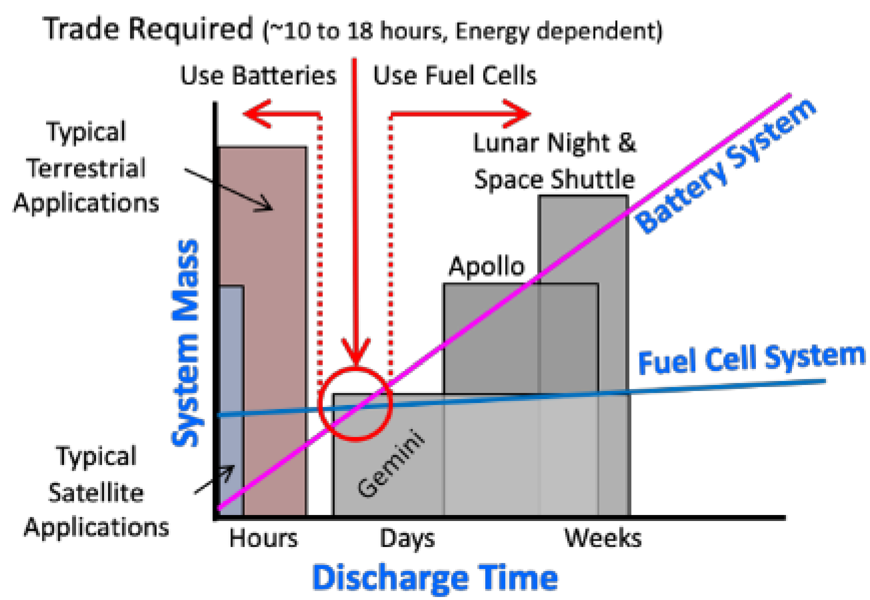
What is an RFC?

An energy storage system that utilizes hydrogen and oxygen gases to store energy



Why?

Higher specific energy (W·hr/kg) for high energy applications where fully packaged battery systems become too massive



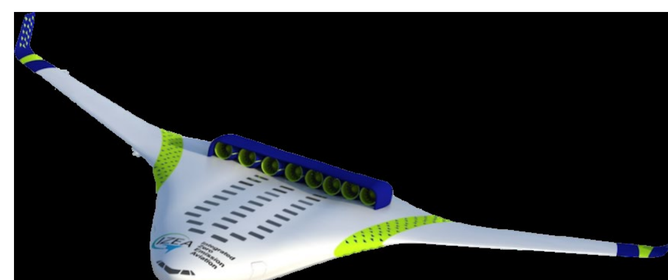
Energy Options for Space Applications	Battery = TRL 9 Primary Fuel Cell = TRL 5 Regenerative Fuel Cell = TRL 3

Fuel Cell Power Generation

- Fuel cells provide primary electrical power
  - Use pure to propellant-grade O_2 / H_2 or O_2 / CH_4 reactants
  - Uncrewed experiment platforms
  - Crewed/uncrewed rovers
  - Electric aircraft / Urban Air Mobility (UAM)
  - Lunar/Mars Landers
  - Lunar/Mars Surface System
  - Venus atmosphere sensor platforms

Center for High-Efficiency Electrical Technologies for Aircraft (CHEETA)
Design Study for Hydrogen Fuel Cell Powered Electric Aircraft using Cryogenic Hydrogen Storage

Concept H_2-fueled Aircraft for the Integrated Zero Emission Aviation (IZEA)
ULI activity led by the University of Kentucky

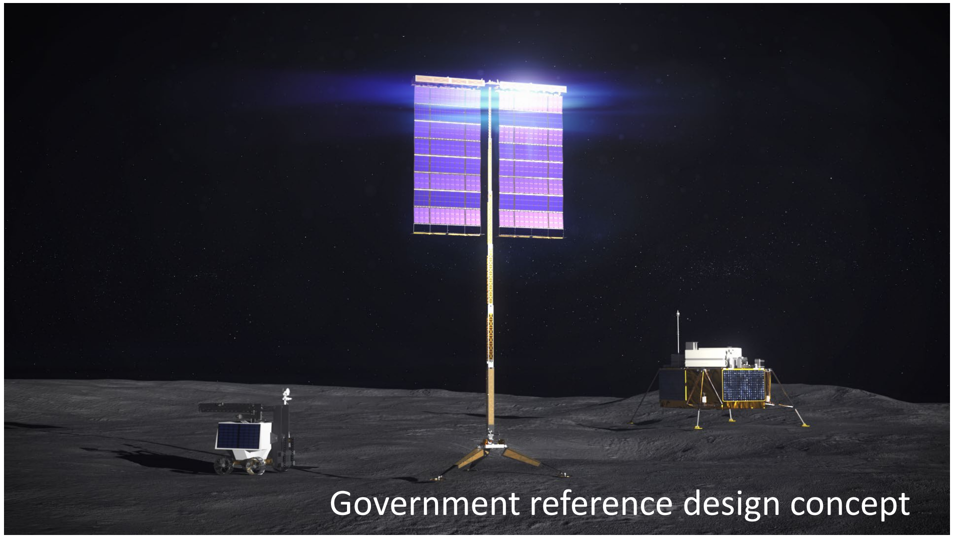


Blue Origin Lunar Lander Baselined Fuel Cell Power as primary power source

Solar Array Development – Lunar Orbit & Lunar Surface

- PV Systems will be used to power many near-term lunar missions
- Gateway Power and Propulsion Element (PPE) will be powered by 2 ROSA solar arrays (50 kW class)
- Human Landing System (HLS) includes elements of photovoltaics

- Vertical Solar Array Technology (VSAT) project - autonomous deployment 10kW class systems of 10 meter (at the base of the array) masts, stable on steep terrain, resistant to abrasive lunar dust and minimized both mass and packaged volume for ease in delivery to the lunar surface
- Current efforts include:
  - Astrobotic Technology, Pittsburgh, PA
  - Honeybee Robotics, Brooklyn, NY
  - Lockheed Martin, Littleton, CO



Government reference design concept

- Ultimate goal of deploying one of the systems on the Moon's South Pole near the end of this decade

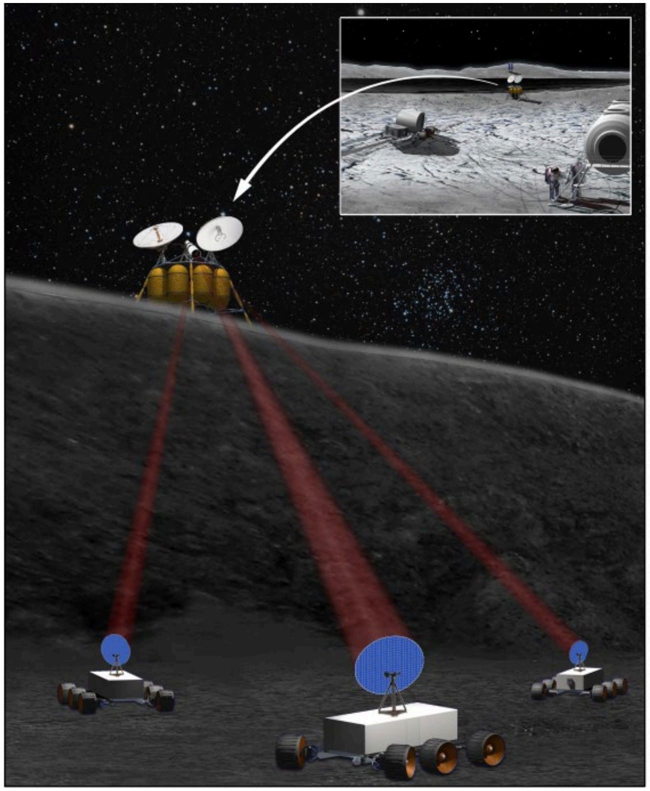
Laser Power Beaming

- Use of laser to beam power to photovoltaic cell allows application of lightweight photovoltaic power to regions with no sunlight

- Particular application being developed is power for multiple rovers operating in permanently shadowed craters near the lunar poles

  GRC is technical lead for Space Technology Research Grant project with University of California Santa Barbara to develop and test laser power beaming as part of the Lunar Surface Technology Research (LuSTR) program

- Impact
  - Technology could enable future rovers in permanently shadowed craters on the moon



Laser power beaming for lunar polar power

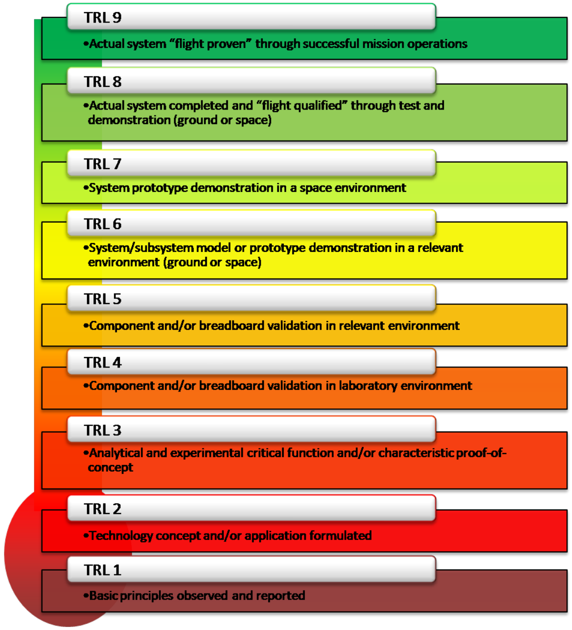
Past, Present & Future Battery R&D Areas

- Increased Wh/kg through system-level weight reduction
- Multifunctional thermal management/packaging
- Reduced parasitic mass & power
- Improved low-temperature cell operability & survivability
- Multi-functionality & integration of energy storage within spacecraft/aircraft structures
- Hybrid chemistry concepts to balance high power + high energy demands
- Hybrid battery/fuel cell/turbine engine concepts
- Modeling efforts to combine battery models with aircraft system-level models to optimize thermal management & mechanical loading
- Lunar survivability studies of different cell and pack formats
- Materials & packaging concepts for improved safety

REVIEW, HELPFUL LINKS & CONTACTS

NASA Public Resources

- Li-ion Batteries for Aerospace
- Solid-state development (SABERS)
- Safety Development w/ SPARRCI
- NASA Engineering & Safety Center
- NASA GRC Power Division
- JPL Power R&D
- Electric Aircraft
- NASA JSC Safety Test Area
- Considering joining the NASA Aerospace Battery Workshop



Thanks A Lot!

GRC Technology POCs

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